Observing Gravity Waves and Drag from Satellite

The Search for Waves at the Limits of Resolution

M. Joan Alexander[1], Laura A. Holt[1], and William M. Putman[2]

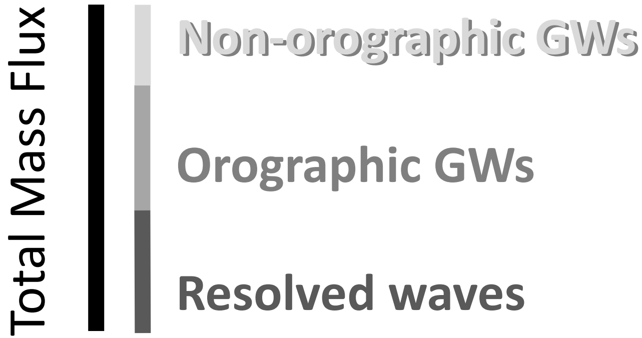
[1]*NorthWest Research Associates*

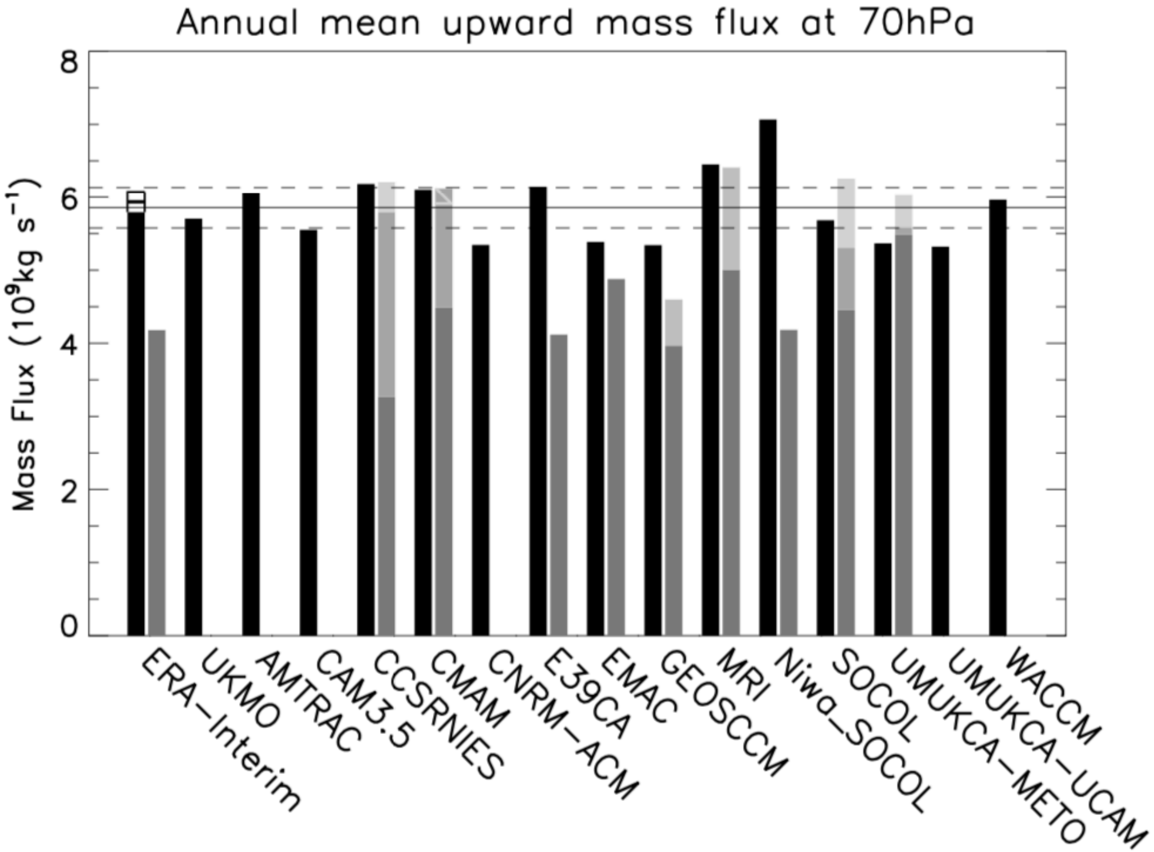
[2]*NASA Global Modeling and Assimilation Office*

Uncertainty in Wave-driving of Brewer-Dobson Transport

Butchart 2014:

- Different wave formulas for driving stratospheric transport circulation in CCMs

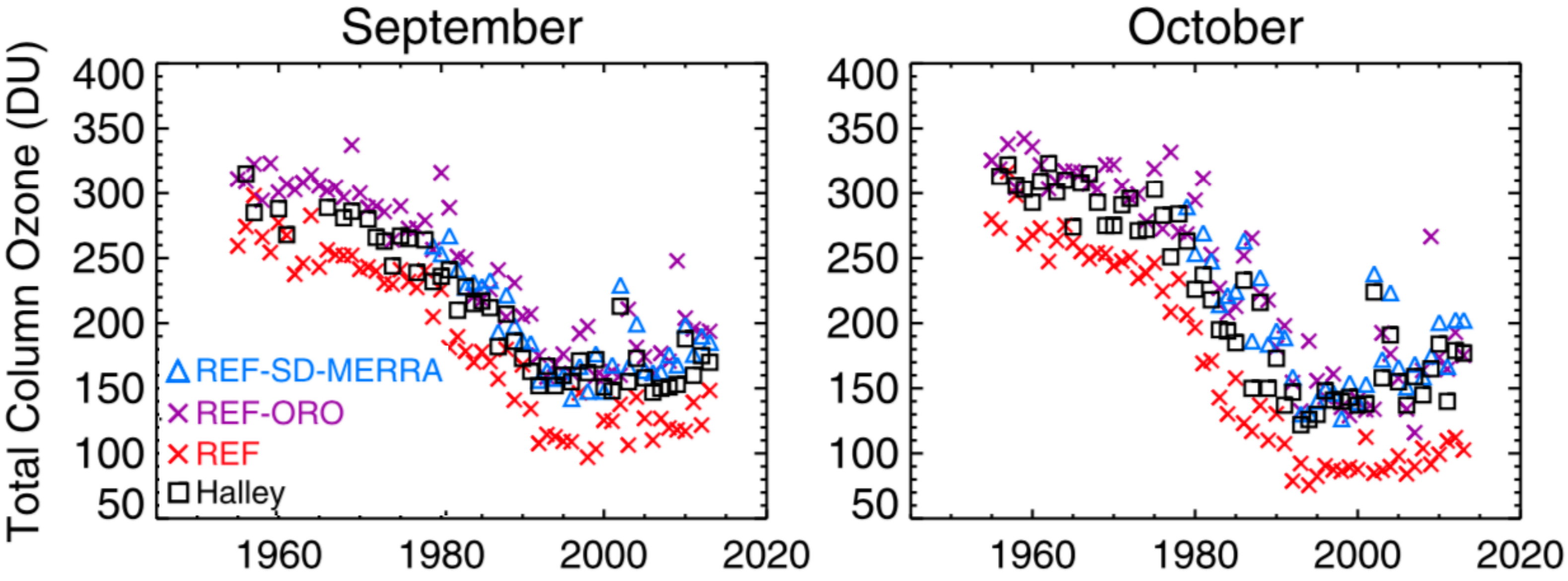




Effect of Gravity Wave Drag on Ozone Variability

Garcia et al. (2017): WACCM simulations

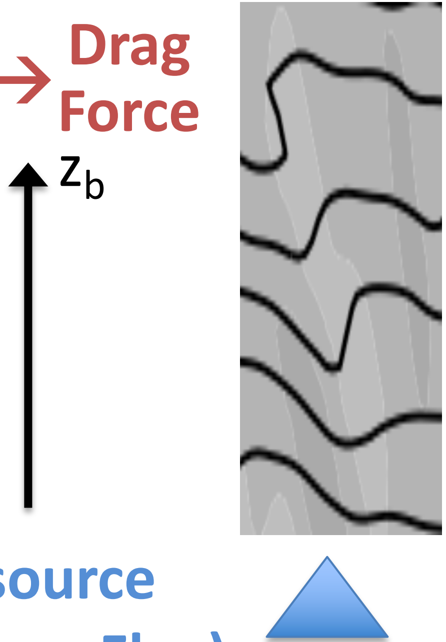
- Artificially doubled orographic gravity wave drag in SH only (x)
- Corrected SH cold-pole problem for improved O_3 observations (□)



Gravity Wave Momentum Flux and Drag

Parameterization in global models

Wave breaking → Drag Force



Flux conserved

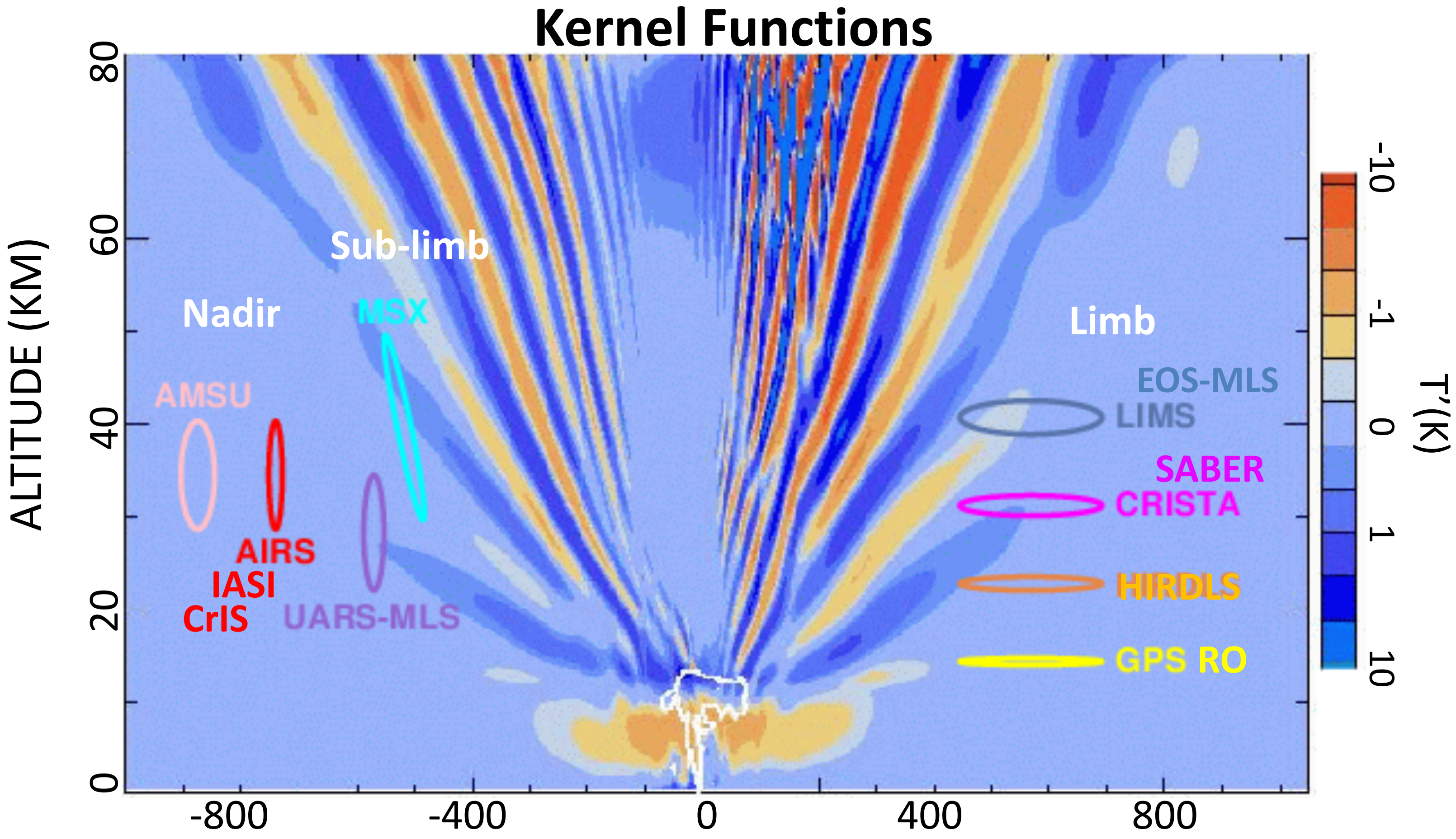
Wave source (Momentum Flux)

$$\overrightarrow{\text{Drag}} = -\rho^{-1} d(\overrightarrow{flux})/dz$$

Momentum Flux from IR or microwave temperature observations requires 3D knowledge of the wavelengths, propagation, and amplitudes:

$$\overrightarrow{\text{Flux}} = \frac{1}{2}\varrho \frac{\vec{k}_h}{m}\left(\frac{g}{N}\right)^2\left(\frac{\hat{T}}{T}\right)^2$$

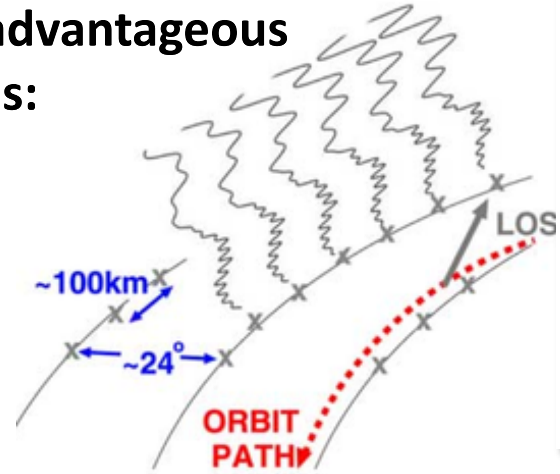
Gravity Waves from Satellite

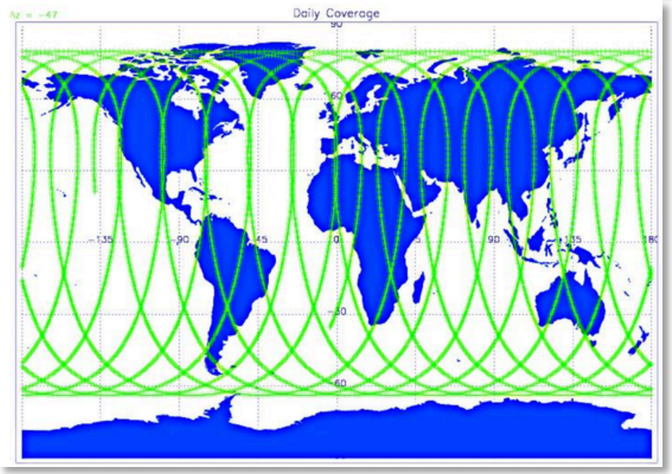


Gravity Waves & Momentum Flux from HIRDLS

Post-launch sampling advantageous for gravity wave studies:

- Single azimuth
- $\sim$100 km spacing
- 64°S – 80°N
- $\sim$1 km Δz





Global gravity wave observations used in a variety of applications e.g.:

- Wright & Gille 2011: Monsoon precipitation sources
- France et al. 2012: Elevated stratopause dynamics
- Ern et al. 2011; Wright et al. 2011: Satellite intercomparisons
- Wright & Hindley 2018: Reanalysis intercomparison
- Wright 2019: Tropical cyclone sources

Comparison of Gravity Waves in Observations and Models

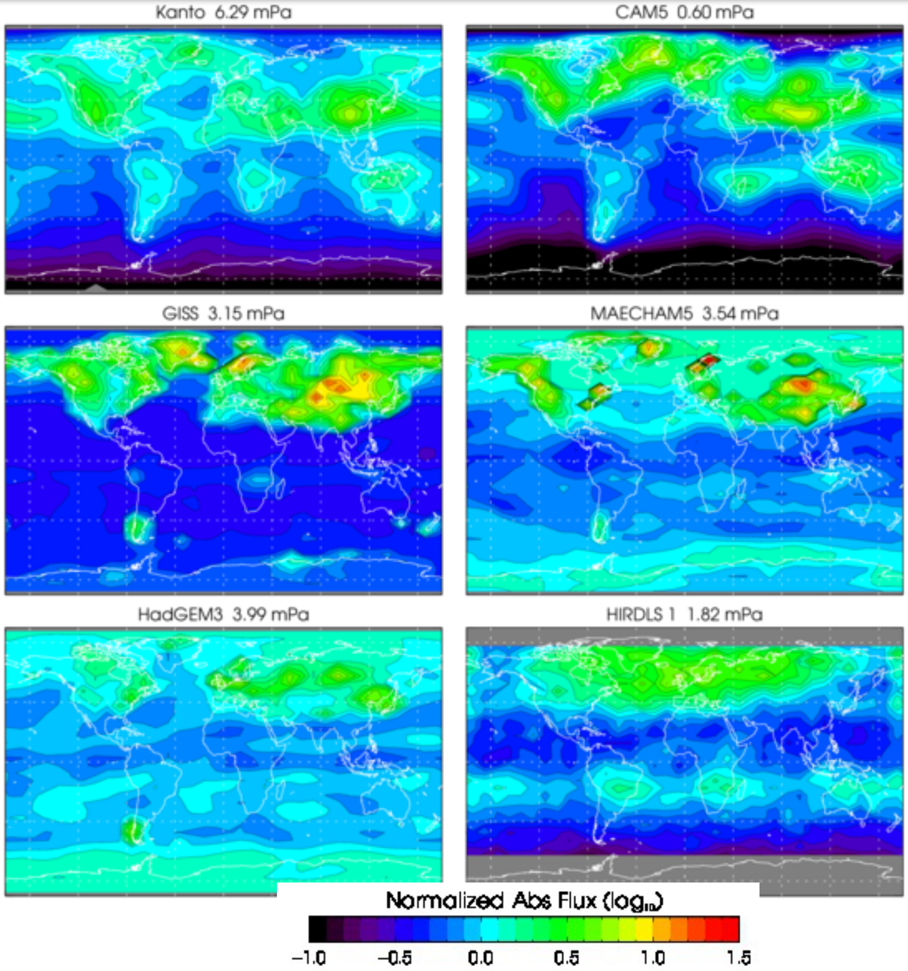
Absolute gravity wave momentum flux [Geller et al. 2013]

Key Conclusions:

1. High resolution models show similar global patterns to observations.

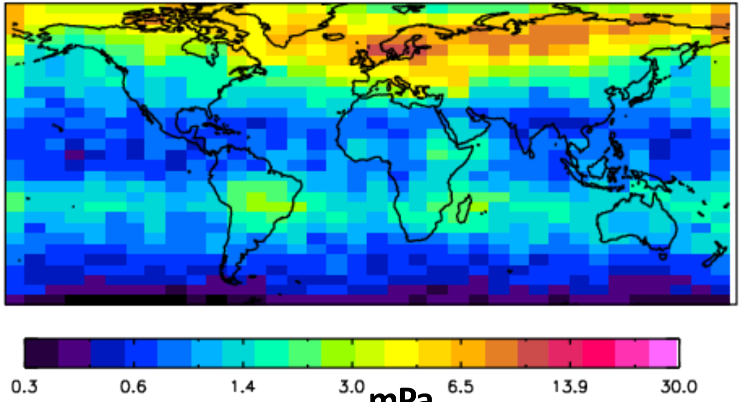
2. Parameterized GW fluxes are all very similar. (constrained by necessary drag on the circulation)

3. Observations are low-biased due to sampling limits (2-5x?)

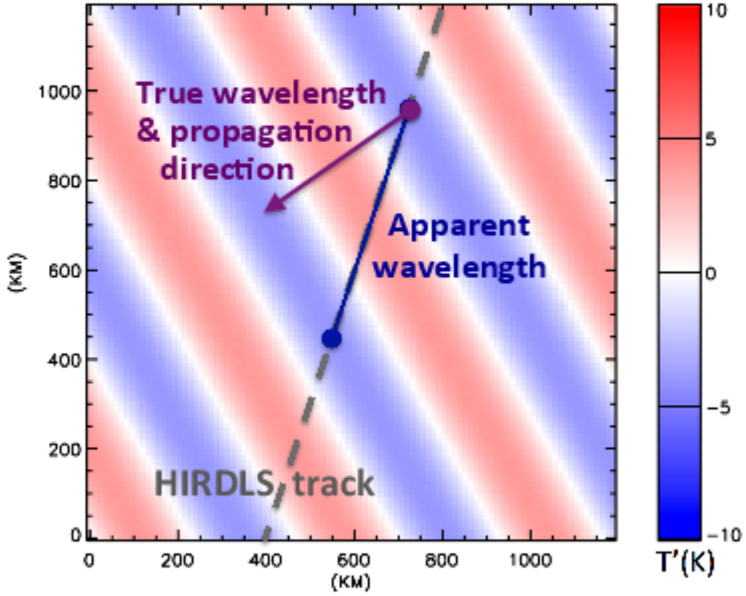


Gravity Waves from HIRDLS

HIRDLS "2D" Momentum Flux



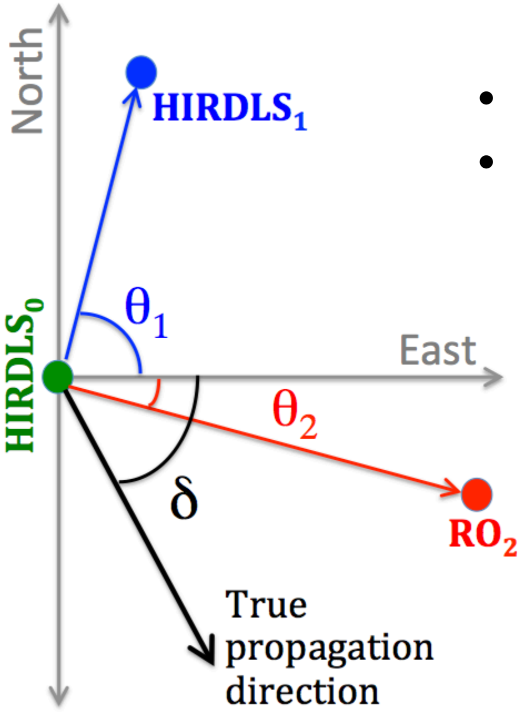
- HIRDLS has best coverage and resolution in lower stratosphere.
- Data is limited to a "2D" approach due to the satellite sampling pattern.



Need "3D" information off the measurement track to correct for this low bias in the momentum fluxes

Combining GPS-RO and HIRDLS

Alexander [2015]



- Find neighboring GPS Radio Occultation temperature profiles
- Combine with nearest two HIRDLS profiles
- Solve for the true direction of propagation using the triad of profiles

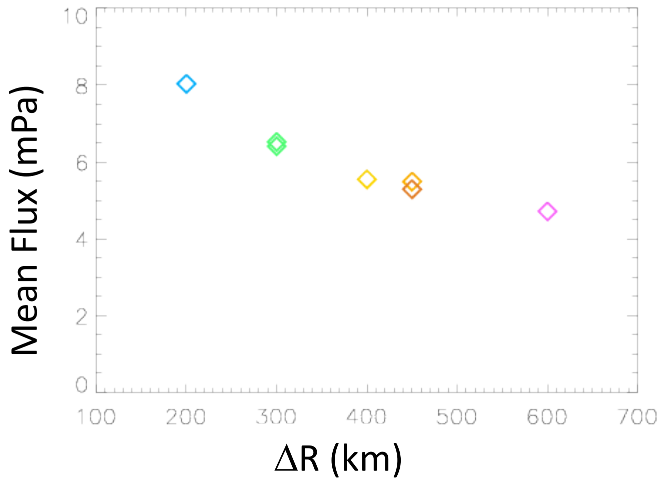
$$\delta = \arctan\left(\frac{\lambda_2 \cos\theta_2 - \lambda_1 \cos\theta_1}{\lambda_1 \sin\theta_1 - \lambda_2 \sin\theta_2}\right)$$

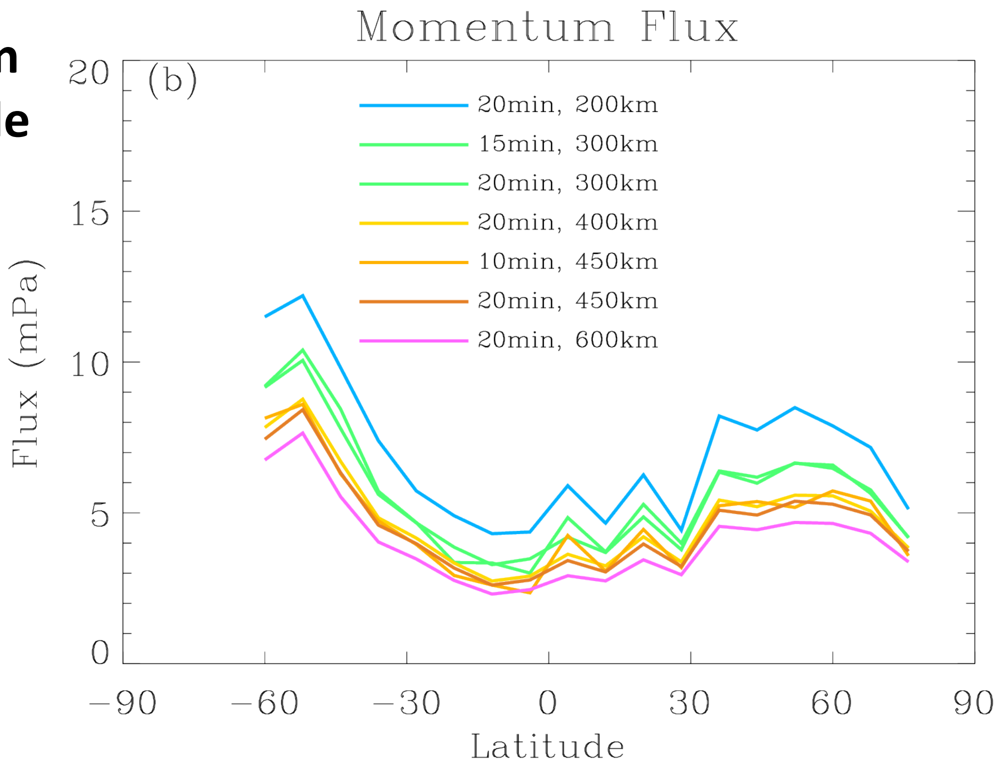
Combined GPS and HIRDLS

Alexander [2015]

Zonal-mean, annual mean momentum flux vs latitude

Results depend on criteria defining "close" profiles.



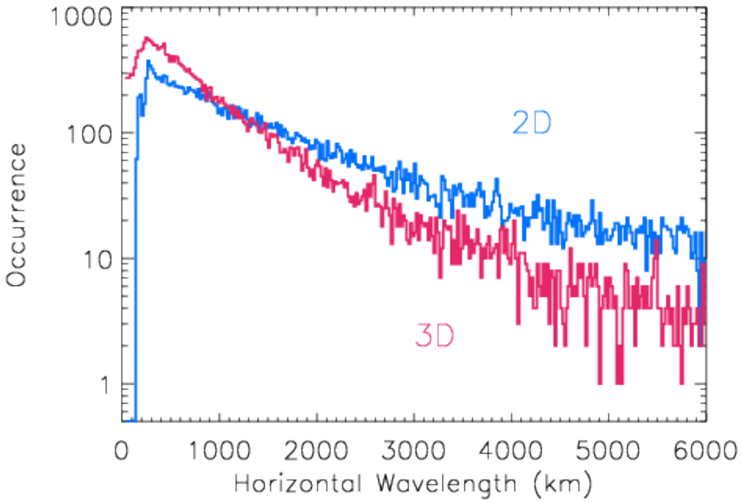


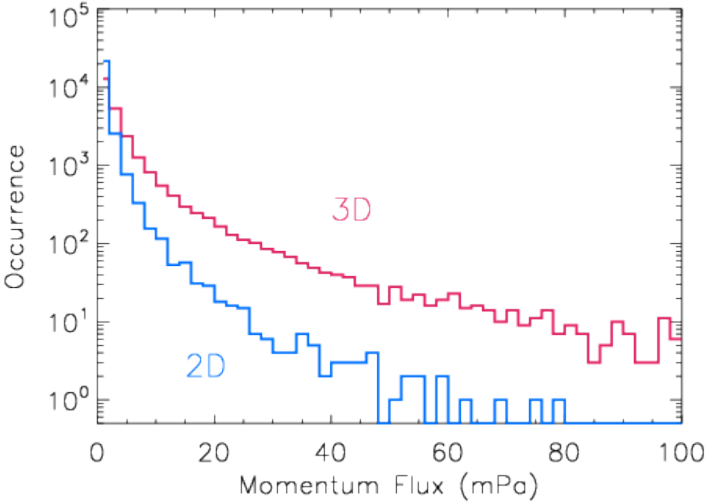
Combined GPS and HIRDLS

Alexander [2015]

Distributions of Horizontal Wavelength and Momentum Flux

2D = HIRDLS-only   3D = HIRDLS+COSMIC





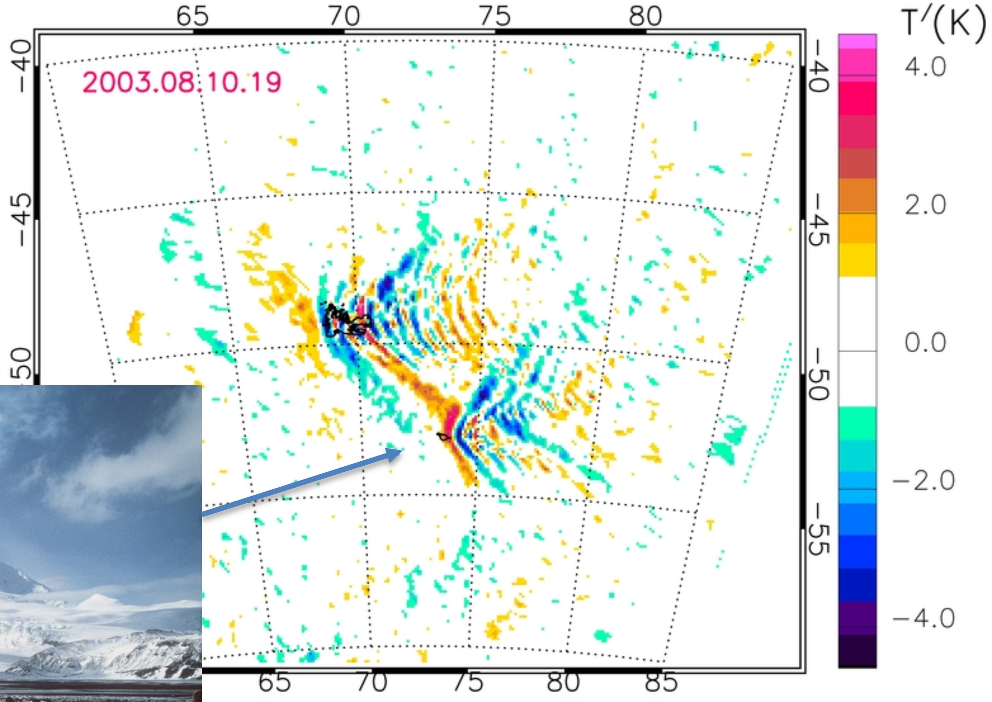
Mean absolute momentum flux increases by a factor of 3.7:

1.7 mPa → 6.4 mPa

- New global average agrees better with models in Geller et al. (2013)

AIRS: Strong wave signals near the limits of horizontal resolution

Orographic Gravity Waves in the Stratosphere at z~40km

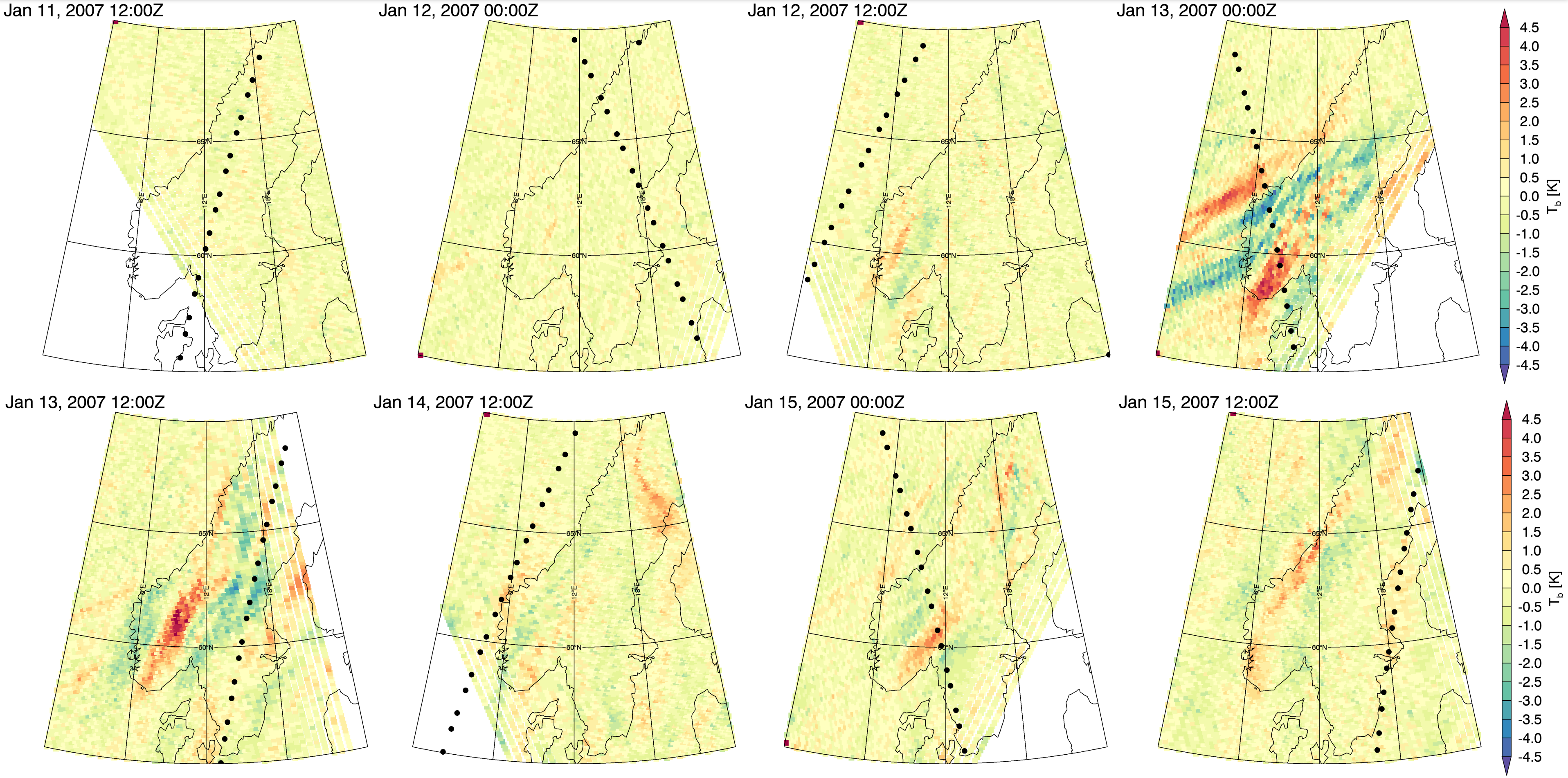


Heard Island

Wavelengths < 40km visible

AIRS Footprint size > 13.5km

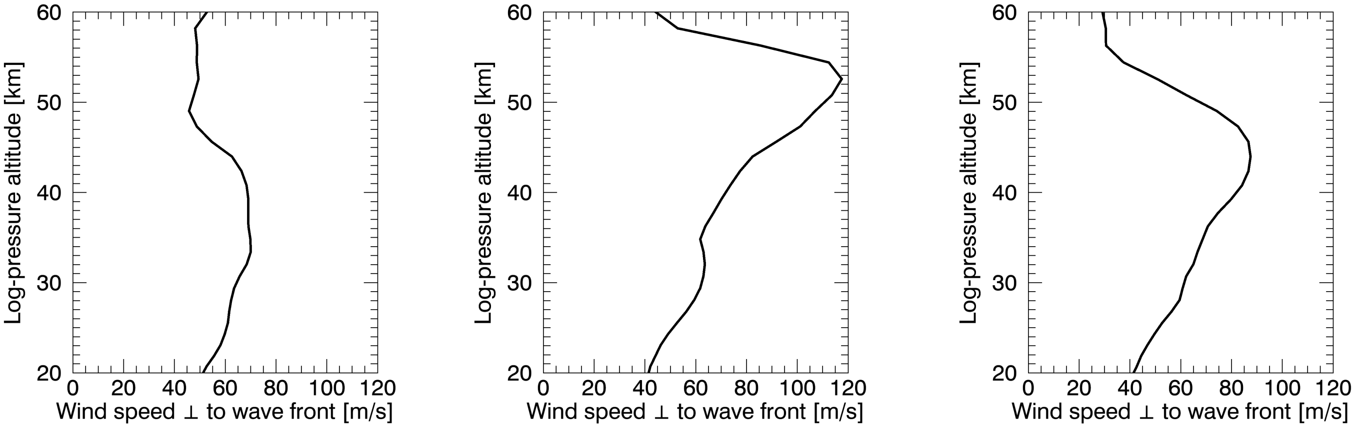
Waves come and go from day-to-day: Stratospheric drag?



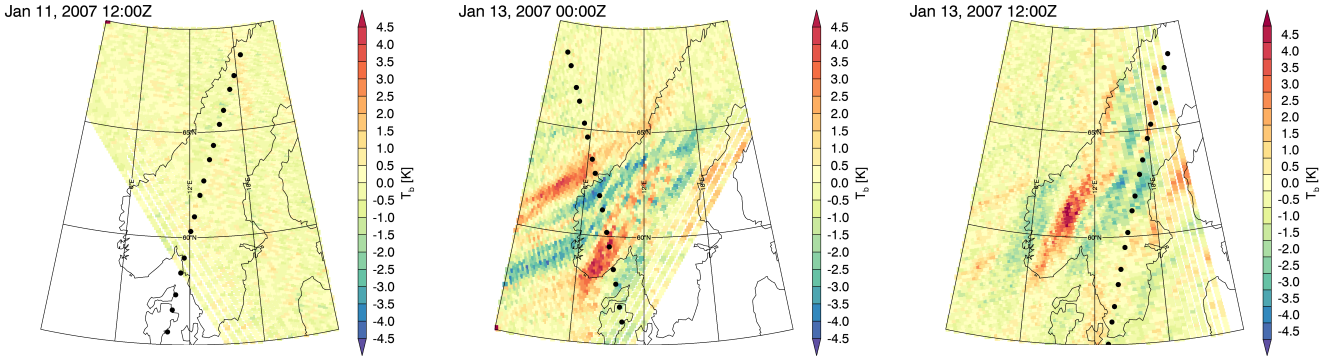
Wind effects on Vertical Wavelength and Visibility

$$m = N/U$$

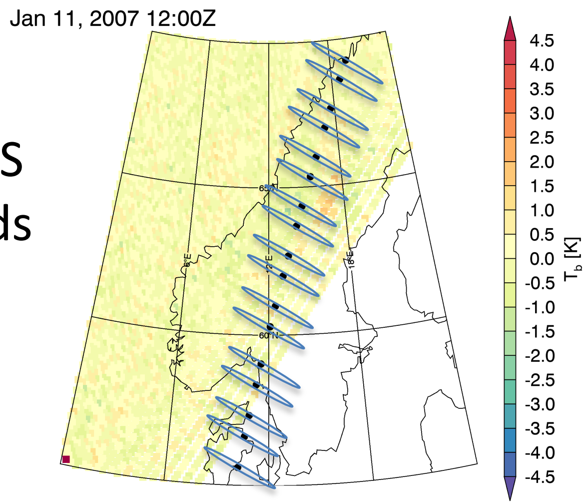
MERRA-2
Wind
Profiles

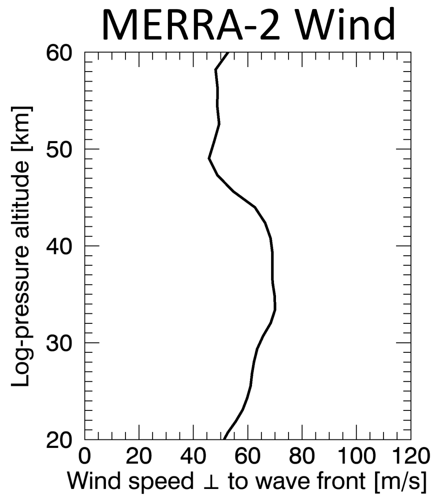


AIRS
Brightness
Temperature
Perturbations

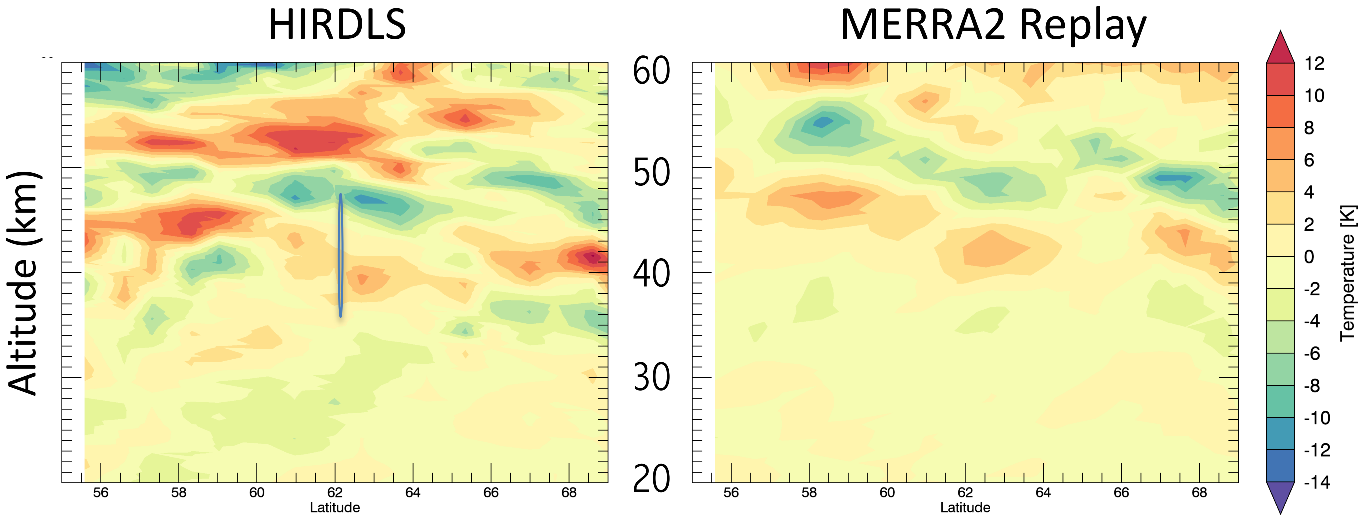


Waves invisible in AIRS because of weak winds and short vertical wavelengths

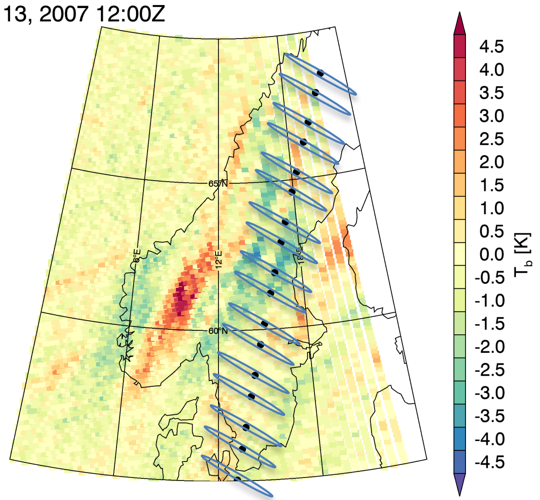


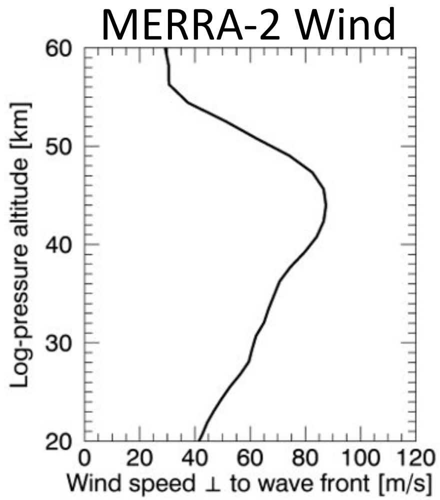


HIRDLS and MERRA-2 show waves with vertical wavelengths ~10-12km (too short for AIRS)

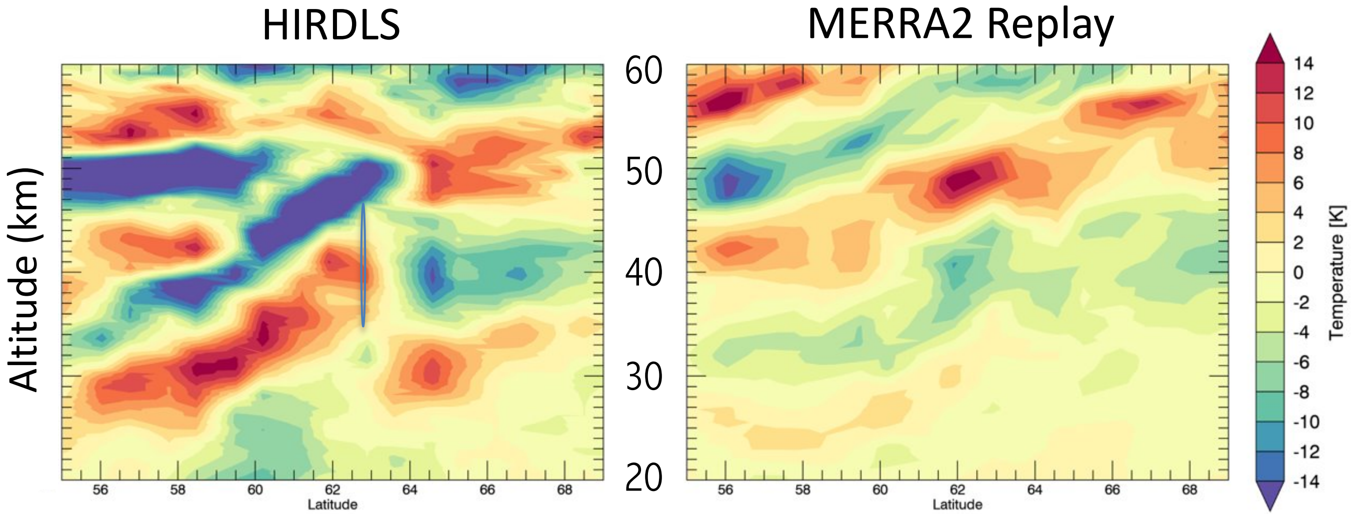


Waves now **visible** in AIRS because of strong winds and longer vertical wavelengths



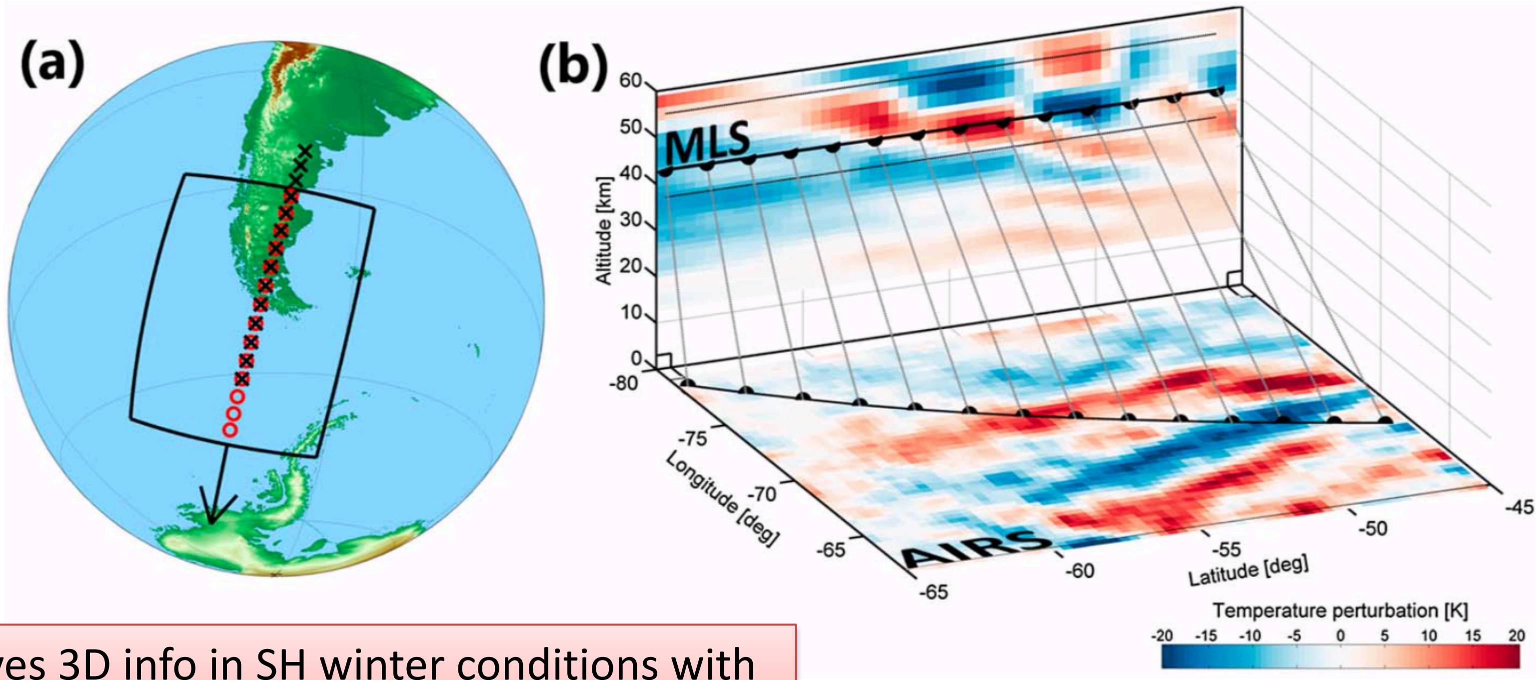


HIRDLS & MERRA-2 show waves with vertical wavelengths ~18-20km (long enough to see)



Wright et al. 2016: Combines AIRS and MLS

Limited to waves that are observed in *both* datasets, which means the coarse vertical resolution of AIRS **and** coarse horizontal resolution of MLS.

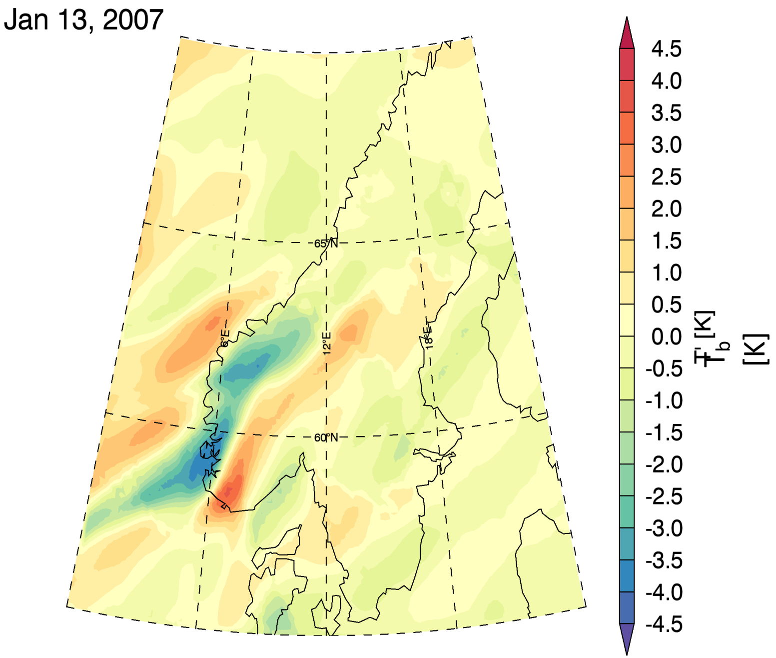


Gives 3D info in SH winter conditions with strong winds = long vertical wavelengths

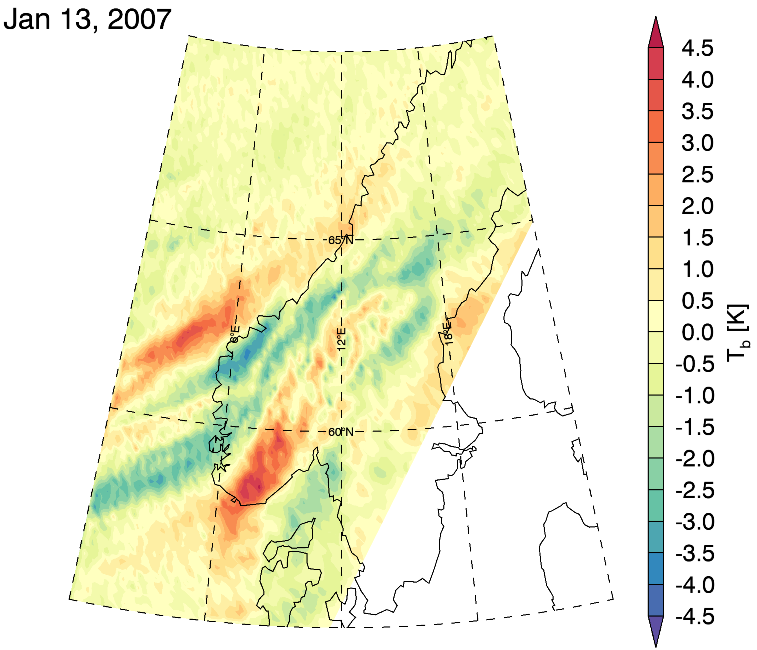
Gravity Wave Resolving "Replay" Simulations

Replay = Very high-resolution GEOS simulations with large scales > 700km relaxed to MERRA-2 reanalyzed fields.

MERRA-2 Replay @ 12 km
Sampled with AIRS kernel function



AIRS
Observation



Summary & Future Directions

Limits of single-satellite observations:

- Each covers only a portion of the wave spectrum
- Can’t infer drag from missing waves due to observational filter effect

Combining different satellite observation methods:

- Useful for obtaining more of the 3-d information → More accurate fluxes
- Still limited by observational filters → Still can’t infer drag

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Future Directions:

- High-resolution "Replay" type models: Can directly validate the gravity waves with satellite observations and derive gravity wave drag directly from these models?
- New 3D high resolution observations? → ALICE!
- Using tracer observations to infer wave breaking and mixing?